New Developments in Sensitivity Testing

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NDIA Fuze Conference

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Lessons Learned from Studying Birds and Bunnies Applied to Building a Better Bomb

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Talk Outline

- Review of sensitivity testing
- Old and optimal sensitivity test designs
- Non sequential designs
- Simulation Results
- Practical Uses of New Techniques

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How Do You Test Explosive Sensitivity?

- Assume each explosive has a unique threshold:
  - » Hit it harder: explosion; hit it softer: no explosion.
- Can't measure detonator initiation threshold, only determine if a stress is smaller or larger than given a detonator's threshold.
- Can only test each sample once:
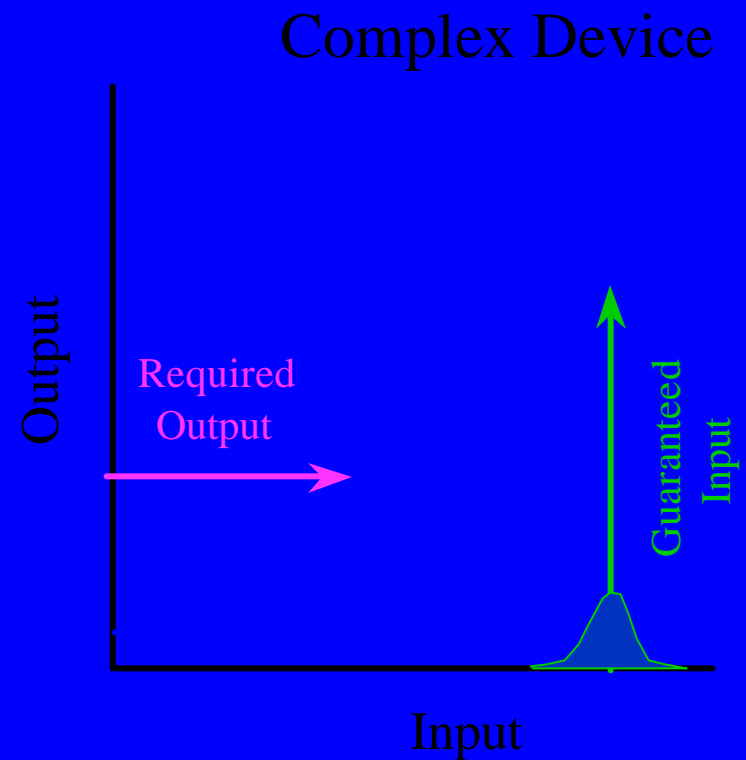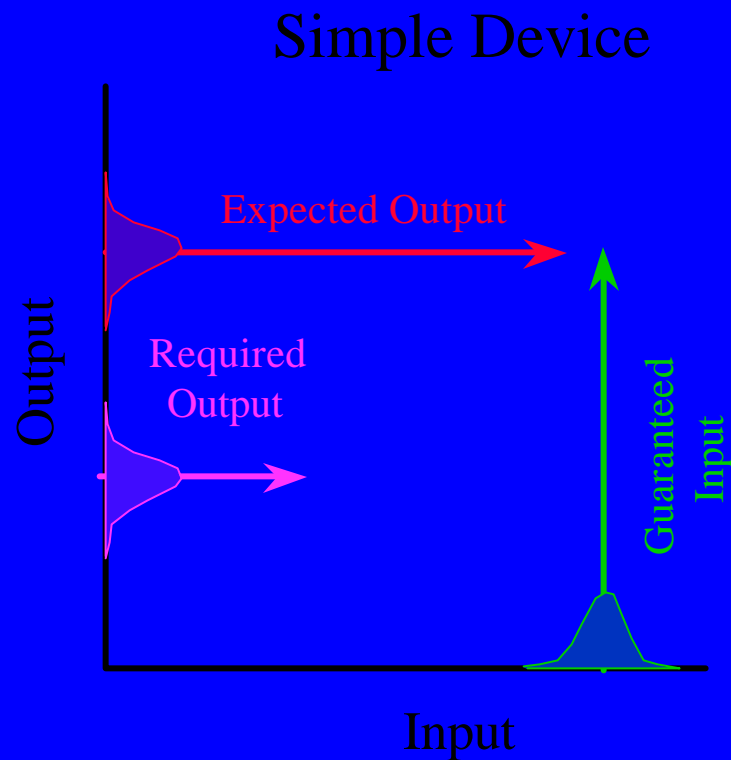 - » Exploded samples gone; unexploded samples changed.

A True Sensitivity Test has These Characteristics:

- Can test each sample only once.
- There is a unique threshold for each sample.
  - Larger stress always leads to response.
  - Smaller stress always leads to no response.
- Function of the thresholds follow known (normal distribution).
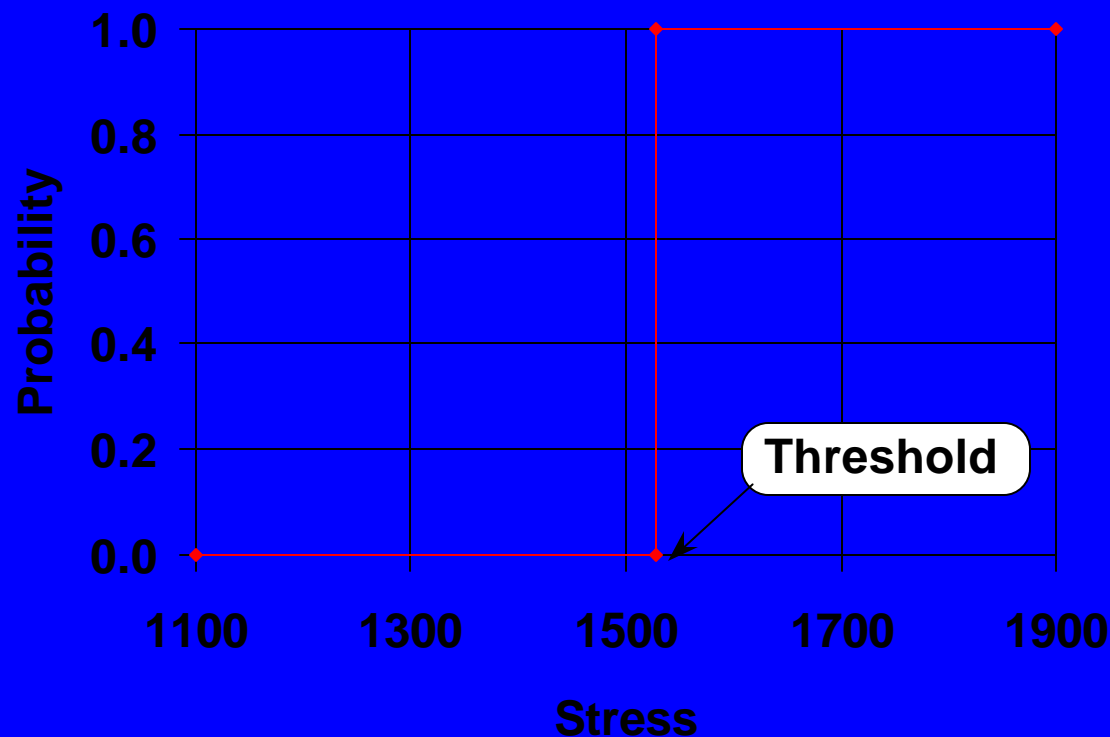- *No duds.*

Sensitivity Test & Analysis Used in a Wide Variety of Fields.

- Explosive sensitivity

- Strength of materials

- Toxicity

- Oxygen deprivation

- Pharmaceutical testing

- Radiation tolerance

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It is Easy to Determine If Simple Devices Meet Interface Requirement.

Simple Device

Complex Device

Output

Expected Output

Required Output

Guaranteed Input

Input
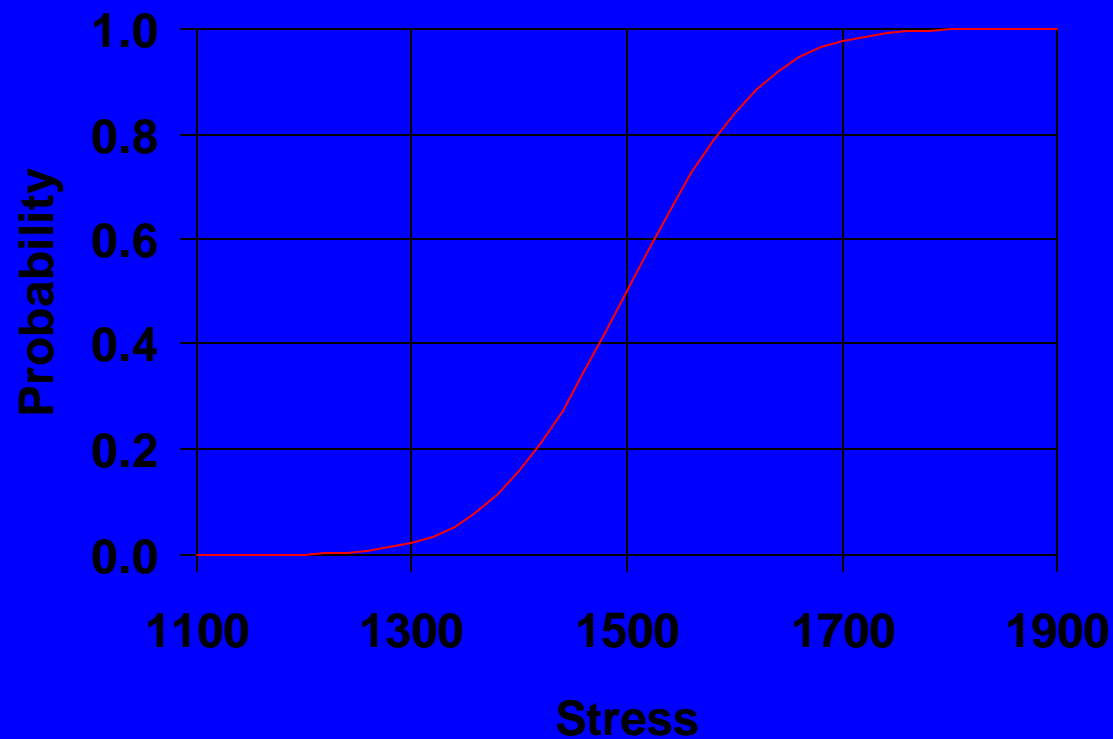
Output

Required Output

Guaranteed Input

Input

Components Respond If the Stress is Larger Than the Threshold.

If Component Thresholds Follow the Normal Distribution:
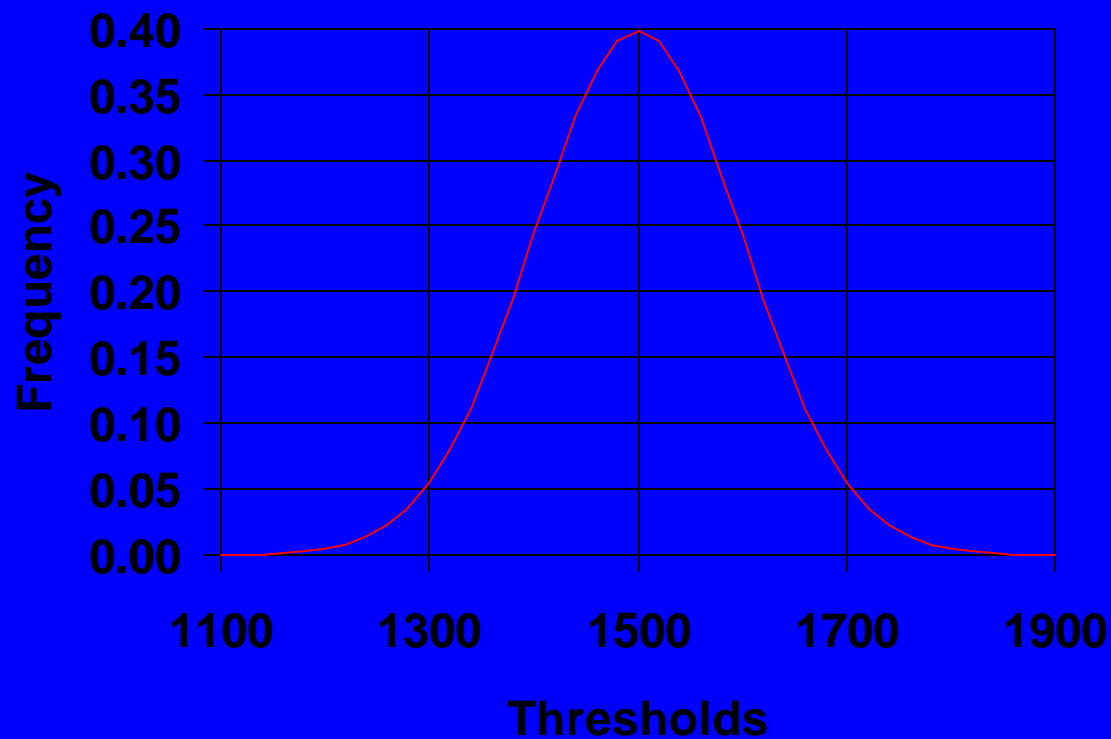
The Probability that a Component Chosen at Random Will Respond is:

What is an Optimal Design?

- All tests not created equal.
- If all responses or failures, you learn nothing.
- Amount of knowledge gained for each test is a function of test level.
- Need to pick test levels to maximize knowledge.
- If you learn the maximum amount statistically possible, it is an optimal design.

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Other Tests Were Designed Many Years Ago.

- Probit Test (1900). Fixed design requires many samples.

- Bruceton (1940). Designed to allow easy computation of estimates of the parameters.

- Delayed Robbins-Monro (1950). Designed to home in on mean of the population.

- Langlie (1960). Designed to give better estimates of sigma when initial knowledge was uncertain.

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The D-Optimal Test Uses a Three Step Procedure.

- Use a modified binary search to find the mean.
    - » Get 1 success and 1 failure as quickly as possible.
    - » Close in on mean.
    - » Check convergence if needed.
- Use guess for Sigma and test for maximum information.
    - » Decrease guess for Sigma until overlap.
- Update knowledge of Mu and Sigma and continue to test for maximum information.

Most Often Explosive Components are Tested Sequentially

- Test equipment is expensive.
- Can only test one component at a time.
- Easy to vary stimulus level.
- Know the results instantly.

- Use knowledge of all N results to pick test level N+1.

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Explosive Transfer Studies are More Complicated

- Vary the donor or acceptor to establish the transfer reliable.
  - VariDrive or VariComp
- Must build components with different explosive density, length, etc.
- Large time delay between knowledge of requirement and delivered hardware.
- Sequential test designs not currently used.

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Similar Test Complications Exist in Biological Experiments

- Instead of supplying the critical **energy** that is sufficient to cause the **device** to **explode**, biologists supply the critical **dose** that is sufficient to cause the **animal** to **die**.

- It often takes days or weeks for the effects of the dose to kill the animal.

- Sequential test designs not currently used.

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Work with Groups Studying Test Designs for Birds and Rabbits Led to New Test Design

- The critical factor is the ability to chose several test levels at a time:
  - Time to determine effects of biological experiments
  - Time to manufacture explosive components
- Design a test that maintains advantages of present D-Optimal design, but allows choosing multiple test levels at one time.

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Modification to D-Optimal Method Allows for Choosing Multiple Test Levels
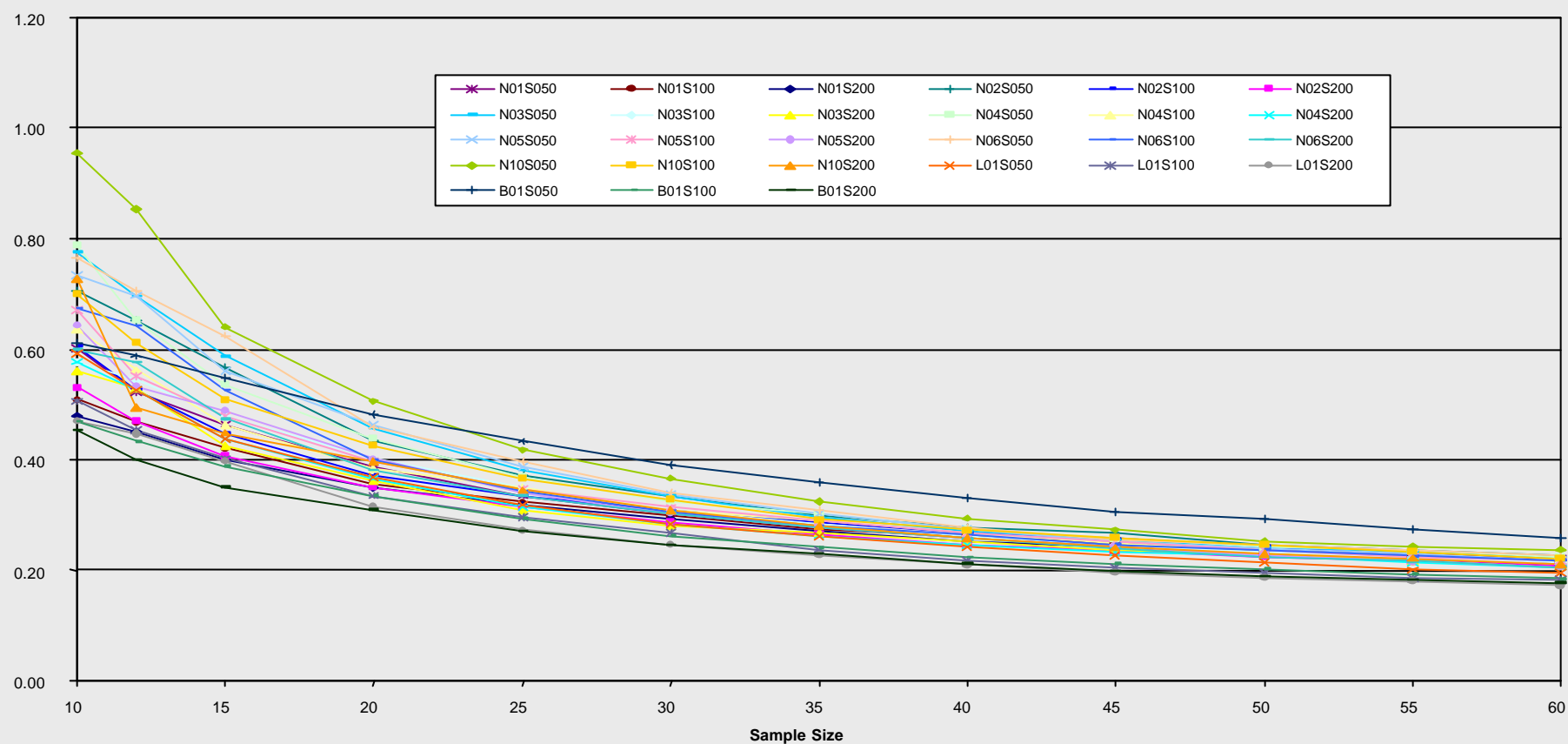
- Use same three population estimates, MuMin, MuMax, SigmaGuess

- First time(s) through spread out test levels uniformly

- When close to SigmaGuess spread out between 2 D-Optimal points

- When levels overlap, place levels at 2 D-Optimal points

Simulation Shows that Modified D-Optimal Method is Very Efficient

- Perform simulation with realistic knowledge of Mu and Sigma
  - Know Sigma within a factor of 2
  - Know Mu within 2 standard deviations
- Look at Mu, Sigma, and All-Fire estimates
- Variance of estimates indicates efficiency
  - Variance has 1/N dependency

Simulations of 1000 Repetitions Were Performed for 27 Cases

Mu Relative Standard Deviation

Legend:
N01S050, N01S100, N01S200, N02S050, N02S100, N02S200, N03S050, N03S100, N03S200, N04S050, N04S100, N04S200, N05S050, N05S100, N05S200, N06S050, N06S100, N06S200, N10S050, N10S100, N10S200, L01S050, L01S100, L01S200, B01S050, B01S100, B01S200
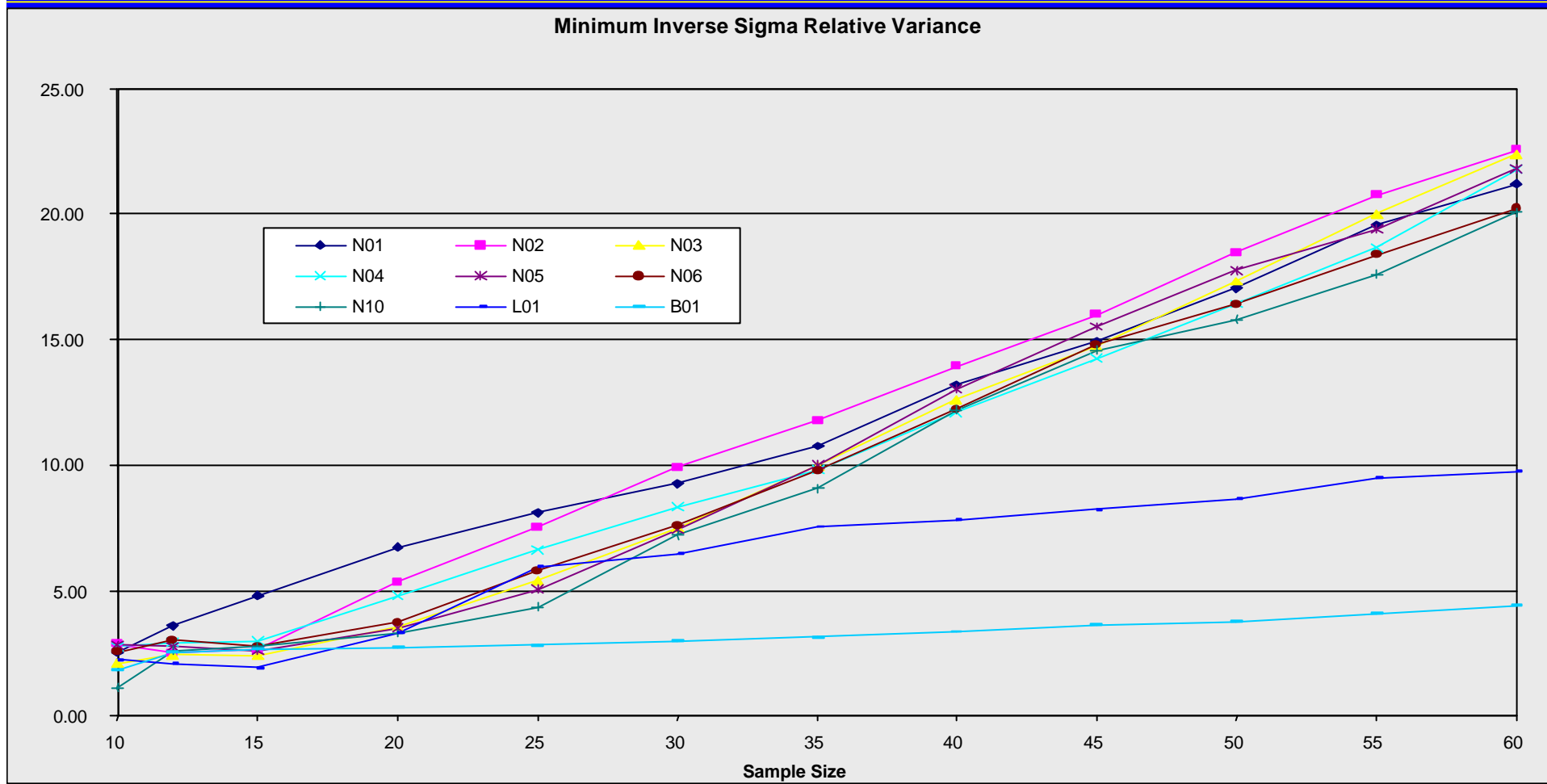
X-axis: Sample Size

Little Change in Mu Efficiency when Picking Up to 10 Tests Simultaneously

Minimum Inverse Mu Relative Variance
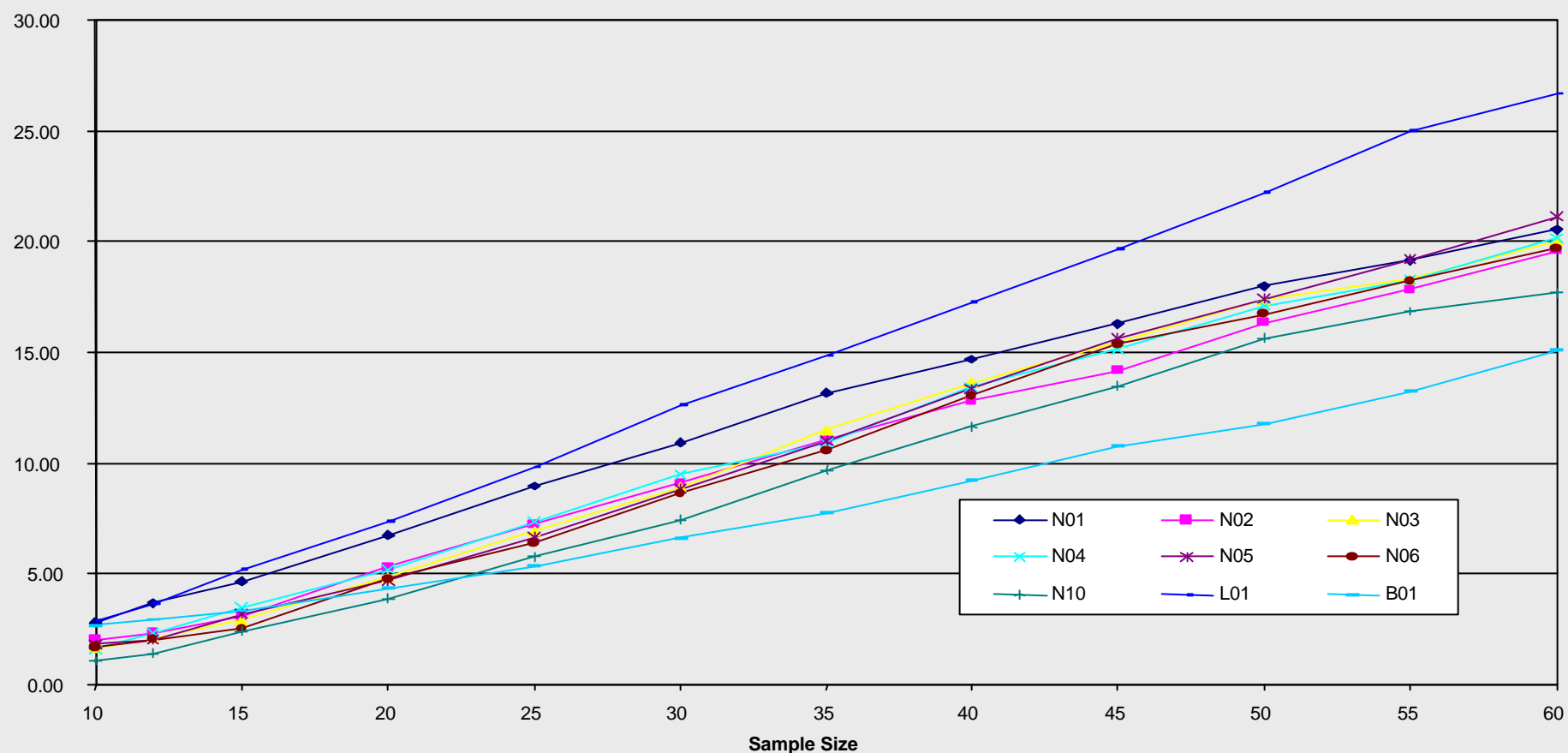
Little Change in Sigma Efficiency when Picking Up to 10 Tests Simultaneously
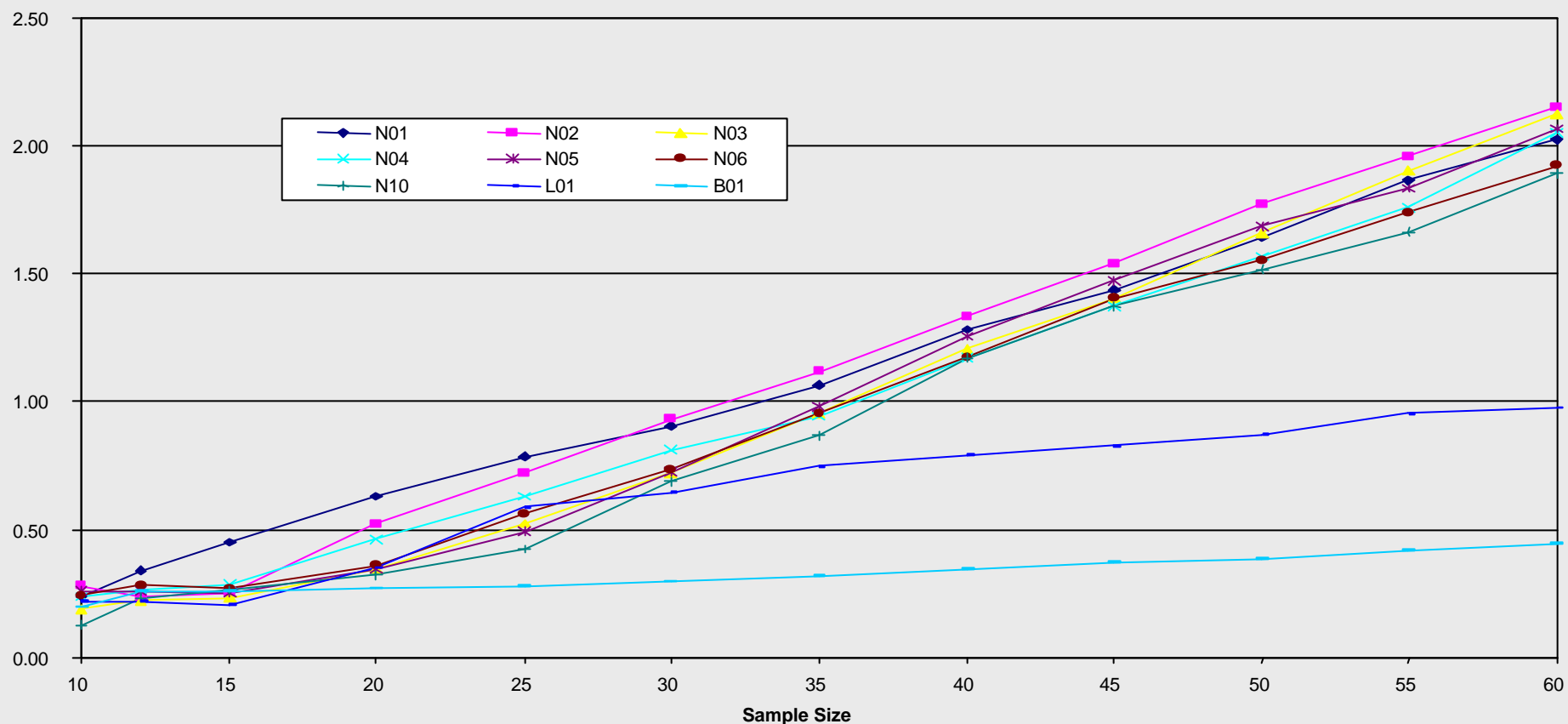

Minimum Inverse Sigma Relative Variance

Little Change in All-Fire Efficiency when Picking Up to 10 Tests Simultaneously

Minimum Inverse Probability Relative Variance

The Decrease in Efficiency Can Be Estimated

- As long as there are at least 4 steps (stages)
  - Simultaneously testing *S* units at a time gives similar results to testing *S-1* less units. (Testing 25 units picking 5 test levels at a time gives similar results to testing 21 one at a time.)
- Mu, Sigma, and All-Fire levels are all better when picking test levels 1 or a few at a time.
  - More simulation with 10,000 repetitions needed to fine tune result

The Modified D-Optimal Test Method Can Be Used In Many Applications

- Whenever it takes time to produce the test levels
  - VariDrive and VariComp experiments
- Whenever the test results are not known for some time
  - Maximum no damage current tests

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